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Aspects of tropospheric structure over the Bay of Bengal during active and break monsoon over India in August 1977

By M. G. Hamilton

(University of Birmingham)

Summary

Details are given of tropospheric conditions over the Bay of Bengal which were associated with break and active monsoon spells over eastern India during August 1977.

1. Introduction

During summer in most years the fully-developed monsoon circulation over India exhibits at least three synoptic patterns, namely, 'moderate', 'active' and 'break' phases. The relative duration of these three phases directly influences human activity because patterns of rainfall associated with these phases differ considerably.

The moderate phase is typified by weak, short-lived and slow-moving cyclones and ridges in the middle and lower troposphere and by an absence of monsoon depressions. A low-pressure (monsoon) trough spans the sub-continent between central Pakistan and Bangladesh. During an active phase, at least one monsoon depression develops over the north Bay of Bengal at the eastern end of the monsoon trough and moves west-north-westwards for 3–10 days. When a break occurs, the axis of the monsoon trough over a wide longitudinal belt either shifts polewards to the Himalayan foothills or disappears below 500 mb as a ridge develops near 20°N. No monsoon depressions develop during this phase. Breaks usually persist for 3–7 days. Therefore, the active and break phases represent synoptic extremes.

Patterns of circulation and cloudiness associated with active and break phases have been compared before (see, for example, Srinivasan and Sadasivan, 1975; Rao, 1976; Hamilton, 1977; Ramaswamy and Pareek, 1978) but aerological data from the Bay of Bengal have laways been sparse.

During August 1977 an array of ships operating within the MONSOON-77 Experiment provided observational coverage of this region for a short period. Fortunately, this observational effort documented a spell of active monsoon and a spell of break monsoon activity. The following account compares aspects of the dynamical and thermodynamic structure of the troposphere over the Bay of Bengal and Asia near 92°E on one occasion during each of these two spells.

2. Data sources

Radiosonde ascents for 00 GMT were available from stations in India, China, Burma, Thailand and Indonesia, and from the MONSOON-77 polygon formation of four USSR ships centred near 89°E in the Bay of Bengal. Data from seven land stations and the northernmost and southernmost members of the ship array for 16 and 20 August, days when conditions were representative of break and active phases respectively, were used to construct latitude cross-sections of temperature, relative humidity and wind velocity components.

In order to compare tropospheric structure over the Bay of Bengal during each of the three phases the ships' observations were averaged in an attempt to reduce random errors which can occur within a single sounding and to minimize the influence of local phenomena at each ship.

As an aid to analysis and interpretation, daily scene-corrected mosaics of digitized infra-red and visible imagery for 03 GMT (approximately) from the NOAA 5 meteorological satellite were compared with 03 GMT surface charts and synoptic summaries which are published in the *Indian Daily Weather Report*. Further information was available in the form of analysed charts for standard levels from the surface to 100 mb for 00 GMT which were received daily by radio-facsimile from the Regional Meteorological Centre at New Delhi. Charts published by a number of meteorological services also were used.

Since data from organizations which employ different radiosonde systems and different schemes of correction for lag and radiation effects are used there is likely to be a problem of data incompatibility, especially in the upper troposphere (Finger and McInturff, 1978). Additionally, station-based errors of measurement and calculation of an ascent as well as errors arising during communication of the coded message can occur. To produce a reasonably consistent analysis, gross errors which would produce misleading and unrepresentative observations at a station were removed by comparing each observation (a) with preceding and subsequent 00 GMT observations at that station, and (b) with simultaneous observations from nearby stations. Missing data were replaced by the mean of the 00 GMT observations for the previous and succeeding day, if these were available.

This scheme does not eliminate all sources of error. Systematic errors and small, but possibly significant, random errors could remain. However, it is considered that the analyses discussed in this account provide a reasonably accurate description of tropospheric phenomena.

3. Break monsoon, 16 August 1977

During 15–17 August the monsoon trough at the surface lay close to the Himalayan foothills. It extended up to 500 mb with its axis almost vertical. A shallow trough extended along the east coast of India from 22°N to 10°N.

In the lower troposphere a trough between 900 mb and 800 mb moved slowly east across Bangladesh and Assam. Between 700 mb and 400 mb a strong ridge spanned the Bay of Bengal between 5°N and 15°N.

Above 300 mb, a zonally aligned ridge with its axis inclined slightly northwards with increasing height moved steadily from 28°N to 24°N.

On 16 August strong horizontal shear of zonal wind occurred above 250 mb between a westerly speed maximum at 200 mb near 40°N and an easterly maximum at 150 mb and above between 15°N and 20°N (Figure 1). Below 400 mb a westerly current was deepest just south of the monsoon trough near 27°N. A westerly speed maximum occurred at low levels over the ship array near 17°N. The westerly zonal flow was strongest at the ship array on most days between 11 and 21 August. Farther south, weak easterlies flowed along the equatorial side of the ridge near 10°N.

South of the Himalayas the meridional wind below 700 mb was mainly southerly. In the middle

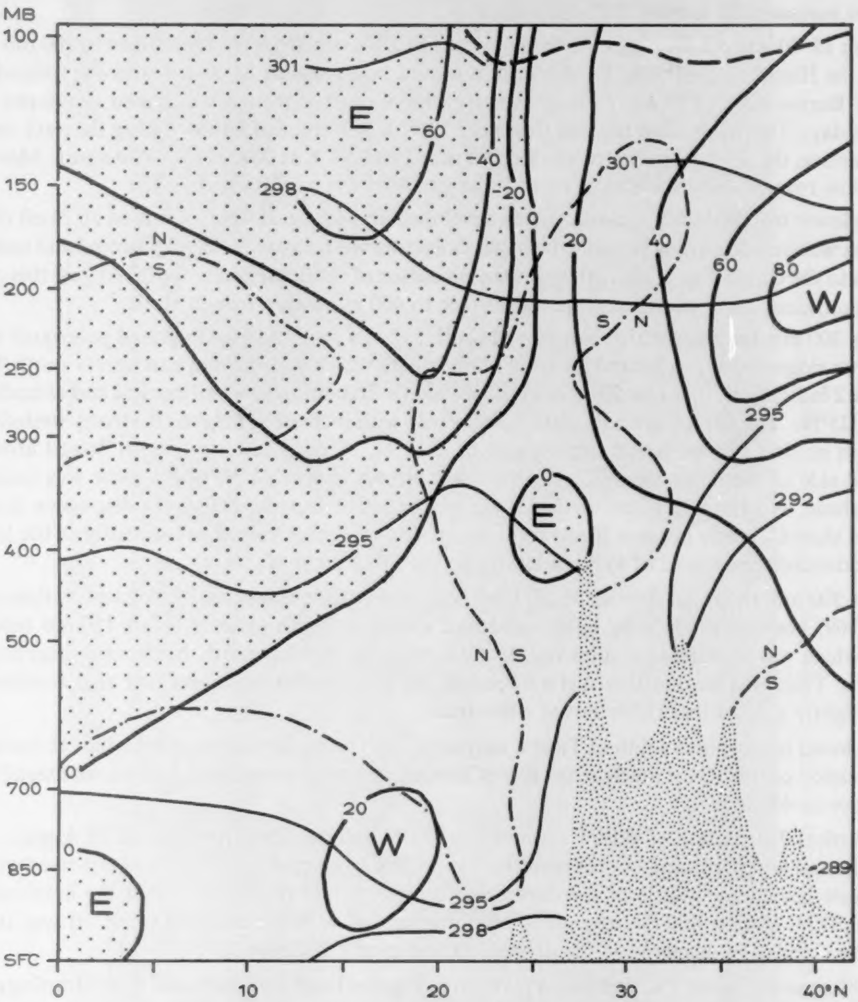

Figure 1. Zonal wind component (knots) and wet-bulb potential temperature (K) for a latitude cross-section near 92°E, 00 GMT 16 August 1977.

Regions of easterly zonal components are shaded. Thin solid lines denote isotherms. Dash–dot line separates regions with northerly (N) and southerly (S) meridional wind components. Tropopause is indicated by dashed line.

troposphere winds were light and variable. Between 300 mb and 200 mb confluence between an east-south-easterly flow south of 15°N and east-north-easterlies over north Bay of Bengal is indicated.

The vertical profile of wet-bulb potential temperature (WBPT) north of 35°N was typically extra-tropical. Tropical conditions south of Tibet are indicated by a minimum in the middle troposphere. Evidently, convective instability was well marked over north Bay of Bengal and north-east India. The meridional gradient of WBPT was small, except over north Tibet below 300 mb.

4. Active monsoon, 20 August 1977

During 18–20 August the monsoon trough west of 85°E extended from the surface to 500 mb and lay close to the Himalyan foothills. Farther east, it moved well south of 25° as a depression formed off the coast of Burma near 19°N early on 19 August within another trough which had developed on the previous day. This depression tracked west near 19°N to the coast of Orissa during the next two days. At the surface, the depression centre was located near 19°N, 90°E at 00 GMT on 20 August. Meanwhile, the shallow trough along the east coast of India persisted but weakened slowly.

In the lower troposphere a cyclonic vortex developed on 18 August near 850 mb at 18°N off the coast of Burma within a deepening trough which was extending west across the Bay of Bengal and east across Vietnam to the China Sea. This vortex was the precursor of the depression. On 20 August this cyclonic (depression) circulation extended from the surface to 400 mb with a trough aloft.

Above 300 mb, the ridge which had moved south to 24°N by 17 August migrated polewards to 28°N as another ridge developed behind an amplifying trough which was moving east across north Tibet.

Figure 2 indicates that, below 500 mb, the depression's circulation was well marked and extended from 10°N to 25°N. The depression axis tilted southwards with increasing height. A strong westerly speed maximum occurred in the lower troposphere near 12°N. A deep easterly current flowed around the poleward side of the depression. This current was strongest near 22°N, where there was weak zonal vertical shear. North of 20°N the vertical shear had begun to decrease before the depression developed (data not shown), partly because the lower tropospheric westerlies veered substantially as the low-level trough extended west ahead of the developing low (cf. Raman *et al.*, 1978).

Above 300 mb, the zonal flow south of Tibet was weaker than it was on 16 August (cf. Ramamurthi *et al.*, 1969) because winds were lighter and had veered to south-easterly below 150 mb behind the trough, which was amplifying as it moved slowly westwards. Farther north, horizontal shear across the ridge over Tibet was weaker than before because the circumpolar westerlies had also weakened and veered slightly as the other ridge moved eastwards.

In the lower troposphere south of Tibet a northerly component developed in the winds to the north of the depression centre. Over much of the Bay of Bengal, flow with a southerly component extended from the surface to 400 mb.

The vertical distribution of WBPT polewards of 25°N differed little from that of 16 August. But in the middle and lower troposphere between 10°N and 15°N convective instability had increased within the south-westerlies equatorwards of the depression centre. It had decreased within the north-easterlies north of 20°N. Above 400 mb, the meridional gradient of WBPT was again small. It was strongest within the circulation envelope of the depression and over Tibet near 35°N.

The differences between the circulation patterns in Figures 1 and 2 are indicated by contrasting patterns of cloudiness (Plates I and II).

On 16 August synoptic-scale deep convection was confined to India east of 85°E and the equatorial Indian Ocean. The extensive cloudiness over north-western India did not show up brightly on simultaneous infra-red imagery (not shown) because it was shallow and broken.

Four days later, the distribution of relatively clear skies and deep convection over the Bay of Bengal and neighbourhood was very different. Convective activity was weaker in the low-level easterlies polewards of the monsoon trough and embedded depression whereas it had strengthened within the low-level westerly current to the south (cf. Srinivasan *et al.*, 1971; Keshavamurty, 1972). Over much of Tibet synoptic-scale convection had diminished but clusters now covered southern India, Malaysia and the Gulf of Thailand.

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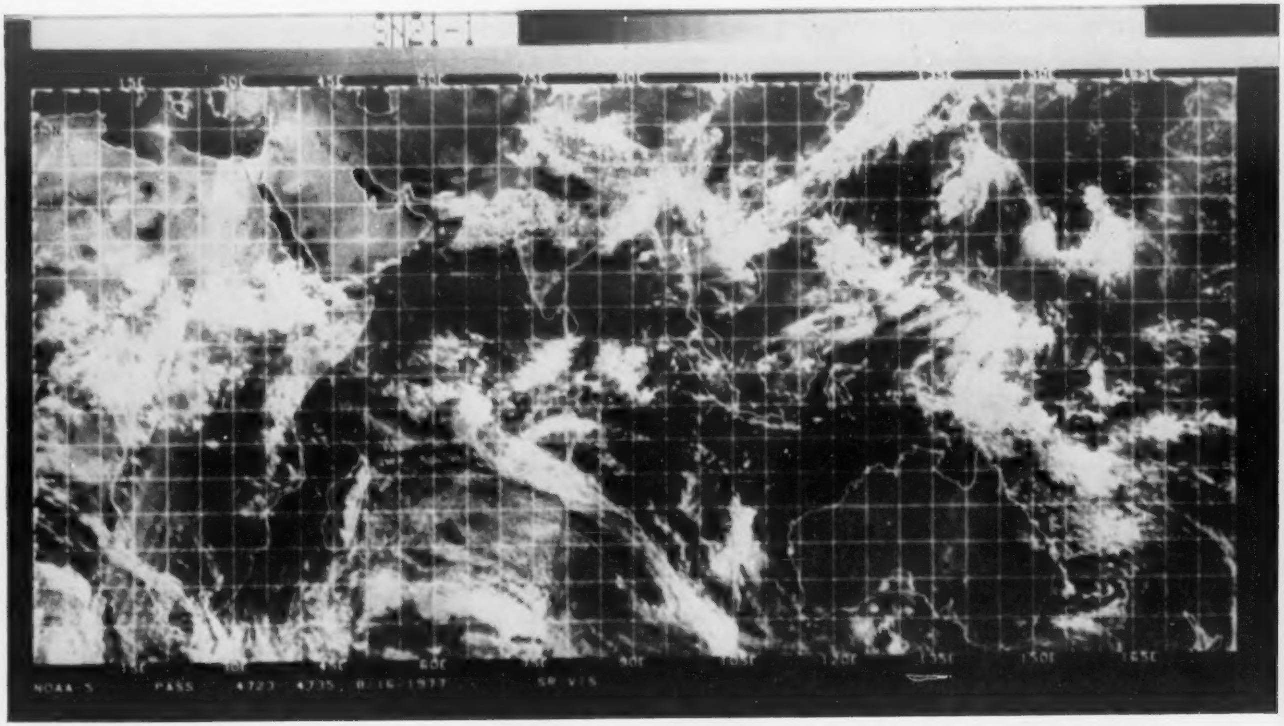

Plate I. Mosaic of digitized scanning radiometer visible imagery (NOAA 5), 16 August 1977 (approx. 03 GMT at 90°E).

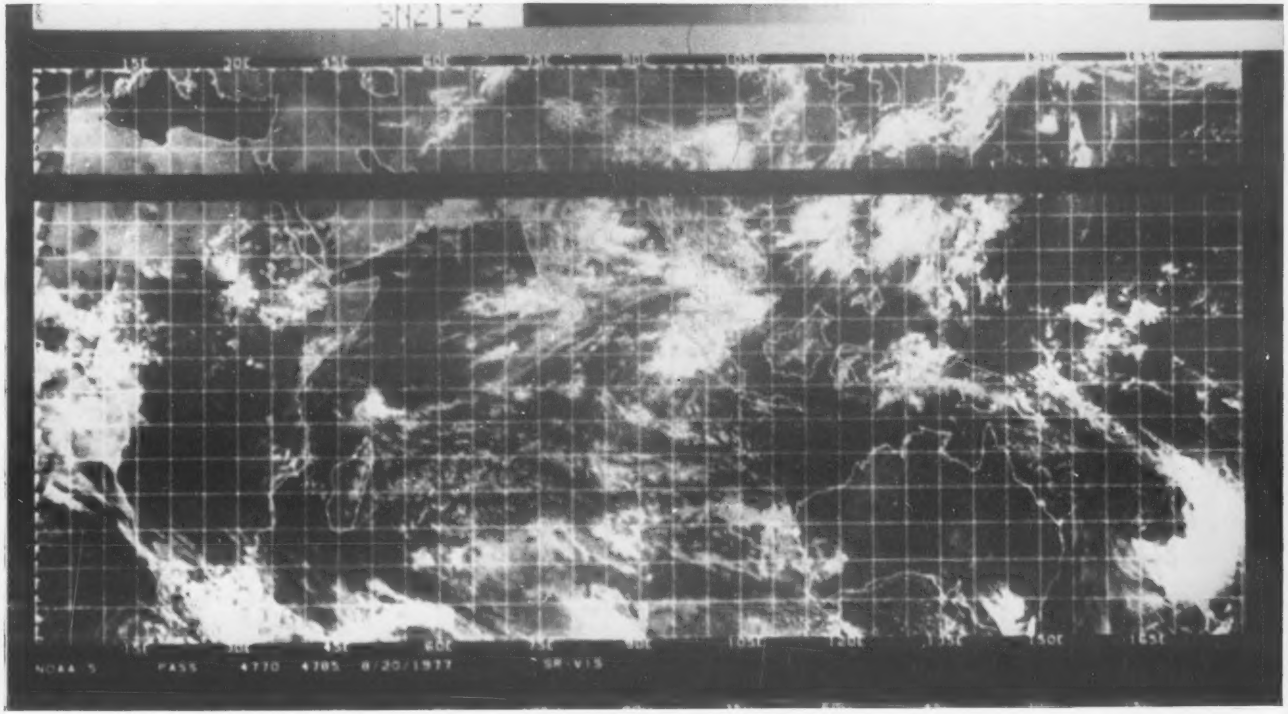

Plate II. Mosaic of digitized scanning radiometer visible imagery (NOAA 5), 20 August 1977 (approx. 03 GMT at 90°E). Horizontal dark band near 25°N is an artefact.

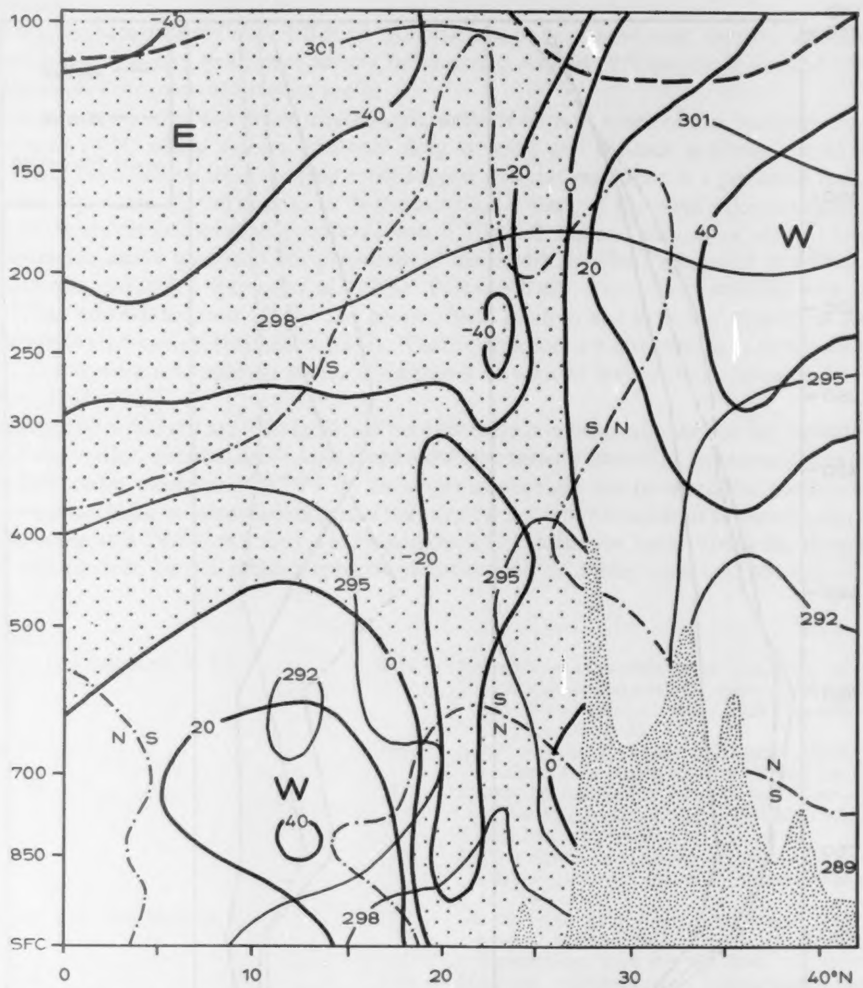

Figure 2. Zonal wind component (knots) and wet-bulb potential temperature (K) for a latitude cross-section near 92°E, 00 GMT 20 August 1977. Legend as for Figure 1.

5. Thermodynamic structure of the troposphere at the MONSOON-77 ship array

After remaining nearly stationary for several days the ship array moved from near 17°N to 19°N between 16 and 20 August.

Figure 3 shows that the lower troposphere was less convectively unstable when the depression was close to the array than it was during either of the break or moderate (12 August) phases (cf. Saha and Singh, 1972). The greatest contrast occurred between 850 mb and 400 mb. Differences between the profiles of dew-point depression for each phase follow a less regular pattern.

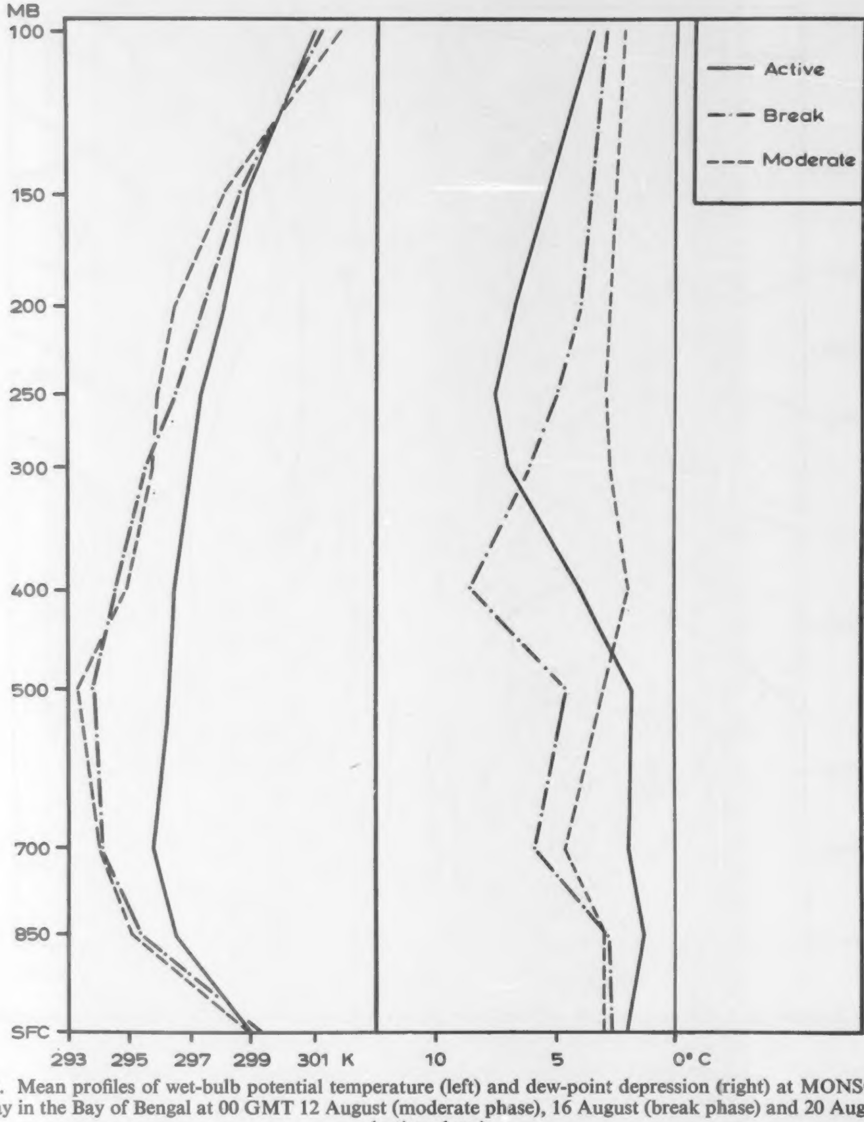

Figure 3. Mean profiles of wet-bulb potential temperature (left) and dew-point depression (right) at MONSOON-77 ship array in the Bay of Bengal at 00 GMT 12 August (moderate phase), 16 August (break phase) and 20 August 1977 (active phase).

During the active phase the 700–400 mb layer was more humid than it was during break but it was noticeably drier near 200 mb. Driest conditions occurred near 400 mb during the break phase. Probably this was due to subsidence within the ridge that covered the Bay of Bengal. During the moderate phase dew-point depression was small and varied little above 500 mb. Vertically averaged dew-point depression was smallest during this phase.

6. Conclusions

In the troposphere over the Bay of Bengal dynamical and thermodynamic features associated with active and break monsoon spells over eastern India during August 1977 exhibited marked differences, despite the short time interval between spells.

The zonal component of the lower tropospheric westerly current south of the monsoon trough was strongest near 15°N, where surface frictional drag is small and contour gradients are likely to be largest. Other observations from the ship array suggest that this maximum is a persistent feature.

When the depression moved near to 19°N the meridional shear of the zonal wind strengthened considerably in the middle and lower troposphere south of Tibet. Simultaneously, zonal vertical shear south of the depression centre increased but polewards of the centre the shear decreased as a deep easterly current was established (cf. Raman *et al.*, 1978). Below 500 mb, convective instability was enhanced near 15°N but was weaker near 22°N. The geographical location and extent of cloudiness associated with each phase were typical (Hamilton, 1977). These differences are attributable to enhanced cyclonic vorticity, convergence and uplift at low levels within a very moist layer during cyclogenesis (Ramage, 1971; Rao, 1976).

Differences above 400 mb are less significant because there is considerable day-to-day variation of the latitudinal and vertical distribution of wind speed within the easterly current (Krishnamurti and Rodgers, 1970). Additionally, estimates of WBPT for the upper troposphere can be unreliable because humidity measurements are liable to systematic errors in very dry or very moist conditions at these levels (Hooper, 1975). However, it is clear that changes in tropospheric structure over India during the summer monsoon are accompanied by well-defined synoptic variations within a deep layer over the Bay of Bengal.

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Quality control of anemograph data

By G. W. Bryant

(Meteorological Office, Bracknell)

Summary

The detection of instrumental errors in anemograph data presents special problems because of the variability of wind measurements in time and space in response to the synoptic situation and local topography. A successful technique has now been devised and a description of its application to the detection of errors in measurements of wind direction is presented, together with an account of some of the results.

1. Introduction

Every month, the Meteorological Office receives hourly values of wind and gust speed and direction for the whole of the previous month, from about 160 anemograph stations throughout the United Kingdom. This very large quantity of data must of necessity contain a significant number of errors which, until recently, could be corrected only by laborious and time-consuming hand-and-eye methods. In recent years, however, the problem has been greatly simplified by the introduction of computers which permit a wide range of checks and comparisons to be carried out in a very short time. A great deal of effort has consequently been applied to the development of suitable computer programs and by means of range, time sequence and internal consistency checks, it is now possible to ensure that very few significant errors which arise during transcription or keying of the data escape detection.

These techniques are not effective, however, in detecting errors which arise from an incorrectly adjusted anemograph or from such changes in exposure as might occur in the intervals between site inspections. Either event would cause errors to occur throughout the data rather than in a few isolated values. For other climatological data, such a situation could be detected by areal quality control methods which compare the data from each station with those from one or more nearby stations but this is less straightforward in the case of wind data.

However, a quality control technique has now been developed at the Meteorological Office which can detect the presence of errors in anemograph data and estimate both the type of error and its magnitude. The following report describes the technique as it is used in the detection of errors in wind direction measurements, and presents some of the results of its operational use.

2. The anemograph network

The stations in the anemograph network are of high standard and provide, on the whole, very good coverage over the United Kingdom. Most of these stations are equipped with either the Mk 4 or Mk 5 anemograph; thirteen still use a Dines pressure-tube anemometer but these instruments are very carefully maintained. Automatic anemographs are being introduced but these are still very much in the minority. Many of the anemographs belong to organizations outside the Meteorological Office which have an immediate need for wind measurements and provide monthly returns either as a service or in exchange for instrument maintenance. Typically, the instruments are set up at military or civilian airfields, coastguard stations, universities and research stations. The sites tend to have an irregular geographical distribution and to be rather sparse in highlands and other less populated areas.

Every site is carefully inspected for satisfactory exposure before the station is accepted into the Meteorological Office network but since the original choice of site may not have been dictated primarily by climatological considerations, it is almost inevitable that few of them will be free of the effects of local obstruction and topography. In fact, the winds at almost every site are affected to some degree by exposure problems such as the proximity of the site to built-up areas, hills or the coast. This may not be a serious problem because unless the variations are very localized this is precisely the type of information that a climatological station is intended to provide. As already mentioned, though, it makes quality control quite difficult.

3. The first stage of quality control

Anemograph data for each station are sent at monthly intervals to the Meteorological Office where they are keyed to an annual data set on magnetic disc. This stage generates a significant number of keying errors and so the archiving process is accompanied by quite detailed quality control. The tests used, which are listed in Table I, consist basically of range, time sequence and internal consistency checks. The value of each item in the data is confirmed to be within an acceptable range and then compared with the previous and subsequent hourly values, to check for unrealistic time variations. The difference in wind and gust directions and the ratio of wind to gust speed are both checked against fixed limits. This is accompanied by other tests which relate to the particular way in which the manuscript form is completed. For example, zero wind direction is associated only with zero wind speed and no gust speed. Also, the maximum and total hourly wind speed for each day are entered on the form and so may be compared with the results computed from the keyed hourly values.

Errors detected in this way occur at an average rate of about four per thousand items. These are distributed fairly randomly throughout the data with some clustering when a missing digit, for example, corrupts all subsequent data in that line. Correction is fairly simple, though time-consuming, and is usually carried out within a day or two. This process thus proceeds routinely throughout the month and, at the end of that time, the only significant errors remaining in the data should be associated with instrumental faults.

4. Quality control of systematic errors

It is difficult to detect errors in anemograph data by areal quality control methods because, unless the errors are very large, they are easily masked by variations characteristic of the station or its environment. For example, Gunn and Furmage (1976)* have described cases where the wind speed and direction are very strongly influenced by local topography and similar, though smaller, effects must occur at

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* Gunn, D. M. and Furmage, D. F. 1976 The effect of topography on surface wind. *Meteorol Mag*, **105**, 8–23.

Table I. *Quality control tests used on anemograph data (first stage)*

Parameter	Reason for query
Wind speed	Greater than 55 knots
	More than 10 knots from values at adjacent hours
	Zero but gust speed listed for same hour
	Zero but non-zero direction listed
	Total for day not equal to listed value
	Maximum for day not equal to listed value
	Computed number of occasions of equal highest mean speed is not equal to listed value
Wind direction	More than 30° from values at adjacent hours
	Not in range 0–360° or equal to 990 (variable)
Gust speed	Greater than 90 knots
	Ratio to mean speed not in range 1.066 to 3.0
	Maximum value not equal to listed value
	No direction given
	No time given
	Computed number of occasions of equal maximum gust is not equal to listed value
Gust direction	More than 30° from mean direction
	Not in range 0–360°
	Time missing

most stations. In addition, the effective height of anemographs in the United Kingdom varies from the standard value of 10 m up to 18 m, with anemographs at a few stations set even higher. As a result, many stations will show a systematic difference in speed and direction throughout the entire 360° when compared with their nearest neighbours. When the large variations in both space and time associated with the passage of various synoptic features are superimposed then it becomes extremely difficult to detect errors by interstation comparison.

It is important to overcome these problems because faults have been developing in up to ten of the instruments each year. This is, perhaps, not surprising in view of the fact that the anemograph is unique among meteorological instruments in being a mechanical device which is subjected to sudden and violent accelerations. The majority of errors, in fact, occur in measurements of wind direction and can often be related to the occurrence of an unusually strong gust. Instrumental faults should be detected, of course, on inspection of the instrument but the number of stations in the United Kingdom is so large that routine inspections can only be carried out at intervals of 1–2 years. It is necessary, therefore, to devise a method of detecting this type of fault from the hourly data submitted by the station.

Despite the objections, clearly the only method of detecting instrumental errors that seemed likely to be successful was to compare the data from two or more neighbouring stations. Some way had to be found to overcome these problems. There was the advantage, however, that the technique was intended to detect instrumental errors which would be present to the same degree in all data generated while the fault persisted. Variations from hour to hour could be removed by averaging so that if local effects could also be eliminated then any remaining difference between the averaged data at any two stations would indicate a fault in one of the instruments. The problem then resolved itself into one of identifying local influences so that they could be removed in the analysis.

5. Quality control—second level

The method which has been devised is to divide the anemograph stations into sets of three nearest neighbours, with some stations possibly belonging to more than one set, and to calibrate each station by comparison with the other two. Ideally, the technique requires two years of recent data for each station;

only one year is really necessary but since any past errors will have been found and corrected only after a site inspection, data for the most recent year are not always reliable.

If we call the three stations A, B and C then the calibration of A against B involves the computation of the average value of the difference in wind direction at the two stations for all occasions throughout the one or two year period when the wind direction at B is in each of 18 sectors and the wind speed is above 3 knots. Since wind direction is tabulated to the nearest 10°, each sector contains two possible wind directions (0° and 10°, 20° and 30° etc.). If both anemographs have been correctly adjusted then the 18 values which result from this process may be regarded as largely a measure of the steering effect of topography at the two stations. For the quality control program, it is necessary to choose two comparisons (A–C and B–C, for example) in which the second station, common to both, is the one least subject to the effects of topography. Selection of the appropriate comparisons is a fairly subjective process and the comparisons finally chosen tend to be those which contain the lowest values.

An example of the result of this process is shown graphically in Figure 1, where the two stations involved are Leuchars, in Fife, and Bell Rock which is a small islet to the east of Leuchars about 30 km from the coast. The divergences from zero are almost entirely due to the effects of topography at Leuchars. The comparison in Figure 1 shows a bias towards negative values because the two anemographs have different effective heights and because Bell Rock is surrounded by the sea so that the wind will, in general, be veered relative to the wind at Leuchars. In most other cases, the 18 values are fairly evenly distributed about zero and values above 20° are uncommon.

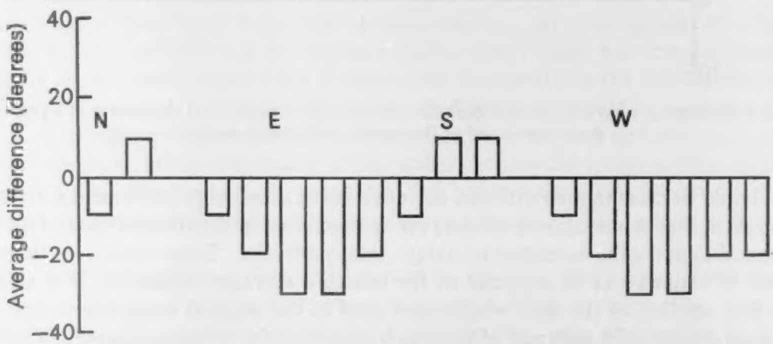

Figure 1. Mean difference in wind direction for each of eighteen 20° sectors for a comparison of Leuchars with Bell Rock.

This fact has been used to detect errors in the archived data before the system is used operationally; Figure 2, for example, shows the effect of an anemograph fault on the values produced by the comparison. The two stations are compared for the first and last six months respectively of the year and the presence of the fault and its approximate magnitude are obvious. The significant feature is that the value for each of the 18 sectors had changed by about the same amount. Except in special circumstances, this type of bias towards positive or negative values usually indicates a fault in one of the instruments and warrants further investigation. Moreover, since each of the three stations is compared with the other two, there should be no difficulty in identifying the faulty station.

When satisfactory comparisons have been found, they are used to 'correct' the differences in hourly mean wind direction at the two stations so that when the average difference is calculated for all sectors

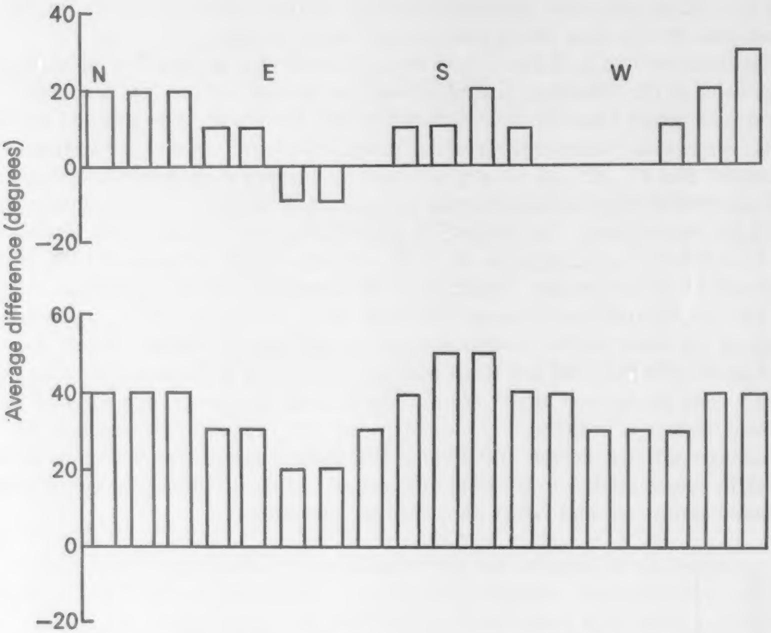

Figure 2. Mean differences in wind direction for each 20° sector for the first and last six months of a year in which a 30° error developed at the second (reference) station.

combined, it should be close to zero with any deviation being ascribed to instrumental error. There is a problem, though, in that in operational use data are analysed for one month at a time and that this is often too short a period to make the averaging technique totally effective. Some measure is therefore needed of the amount of variation to be expected in the monthly averaged difference. For this reason the technique is first applied to the data which were used in the original comparisons and the average difference in wind direction for each pair of stations is calculated for all sectors combined for each month using the corrected values. From the results, which should vary fairly randomly about zero, a value is selected which is exceeded no more than once a year and this is used in the quality control program as a limit to be exceeded before a query is raised. Typical values are 10° to 15°, rising occasionally to 20° for sites where the topography is more complex.

This stage, too, is useful for the detection of errors in the archived data. The case just described, where an error occurred in the middle of the year, produced the monthly mean differences shown in Figure 3. Once again, this type of result indicates a need for investigation.

6. Operational technique

The remaining step is to create the data set which will be used by the operational program. This consists of an entry for each station pair consisting of the two station numbers, their site numbers, the 18 calibration values, the limiting value and two markers, which are initially set to zero.

The comparison program, which requires a different response from the scrutineer than the quality control methods just described, is delayed until the last few days of the month. This program examines

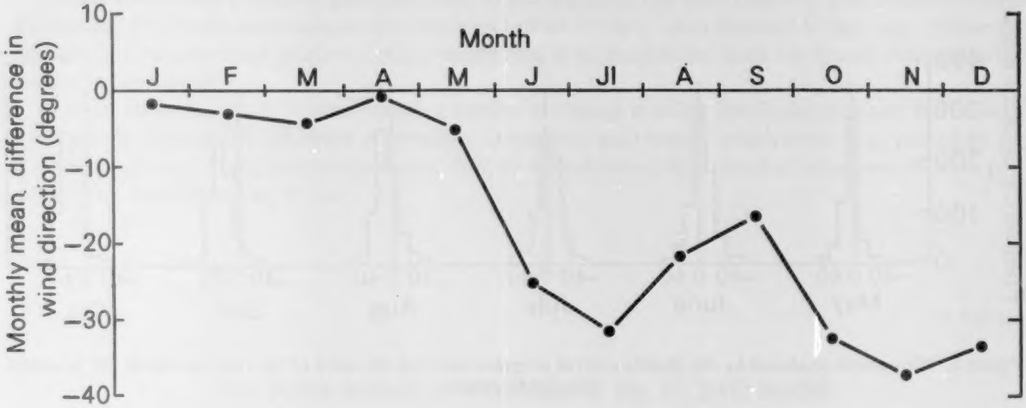

Figure 3. Monthly mean differences in wind direction for the two stations compared in Figure 2.

stations in the groups of three listed in the data set described in the previous section. If we again call the three stations A, B and C in which C is the reference station, then station A is first compared to C. The computer checks all the hourly mean wind directions for the month for the two stations and uses the direction measured at station C to decide which of the 18 adjustments should be applied to the direction measured at A. The adjusted difference for each hour is then computed and the mean and standard deviation of the resultant values calculated. If the mean exceeds the assigned limit or the standard deviation exceeds 30° (a value based on the use of past data), then a query is printed out and a histogram is plotted to show the frequency distribution of the adjusted differences. The process is then repeated for stations B and C.

The histogram is probably the most important part of the program because it contains more information than the basic statistics of mean and standard deviation and it is, in many ways, more convincing. The examples shown in Figures 4 and 5 illustrate this for the two types of direction fault likely to be developed by anemographs. Figure 4 shows the result of a zero shift of 30° in one of the two instruments and the abrupt sideways shift of the distribution, whose shape is otherwise unchanged, is quite characteristic of this particular fault and shows approximately when it developed. Figure 5, on the other hand, shows the effect of a less common situation where the anemograph head has become loose so that considerable backlash had developed. The transition from the fairly narrow Gaussian distribution of the February to April data to the flat, rather distorted distribution of the next three months makes the fault quite obvious.

There is generally no difficulty in identifying the station submitting the suspect data because of the way in which the stations are compared. A fault at station C, for example, will give rise to two queries while faults at either A or B will cause a query to be printed only for the comparison in which they take part.

The limits have been set low enough to be exceeded occasionally by the mean difference in direction even for correctly adjusted anemographs and, in borderline cases, it may be decided to delay any action until the same query has been raised on two or more successive months. To make this easier, the two

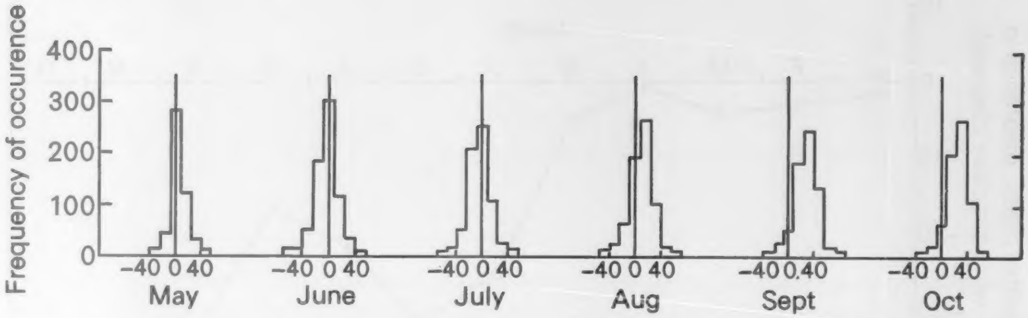

Figure 4. Histograms produced by the quality control program showing the effect of zero shift of about 30° in one of two anemographs.

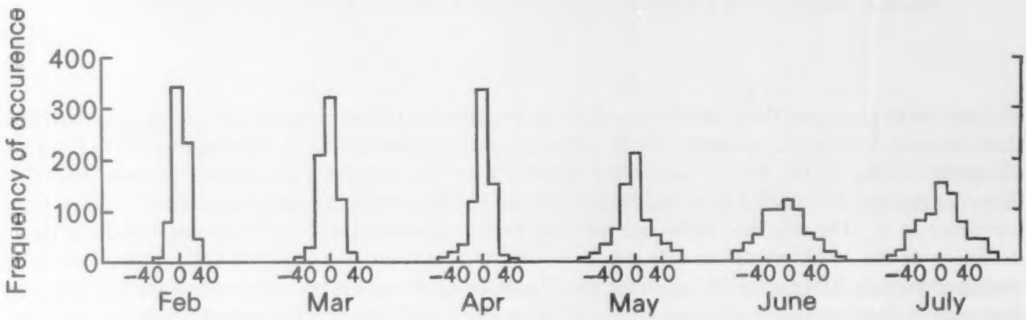

Figure 5. Histograms showing the effect of backlash produced by a loose mechanical coupling in one of the anemographs.

markers on the data set are adjusted, when a query is raised, to show which station was queried and the number of successive months for which the same query has appeared. The values of the two markers are printed out as part of the query message. To prevent the second marker from being incorrectly incremented if it should be decided to run the program for a second time on the same data, a marker is also set, for each station tested, in the anemograph data set.

Summary

Anemograph data received at the Meteorological Office are now subject to quite sophisticated quality control by computer. In particular, the most serious problem of detecting instrumental faults fairly rapidly appears to have been solved. The interstation comparison has now been in operational use for over two years with considerable success. Inevitably, a few stations, mainly in the Scottish Highlands, have not been included because of the magnitude of topographical influences and the lack of suitable reference stations but the majority of stations are tested.

In each case where a definite query has been raised, the fault has been traced to a zero shift or loose mechanical link at the anemograph and errors as low at 10° have been detected in this way. However, changes in exposure could produce similar results and, if no mechanical fault was found, this possibility would be considered.

In order to detect errors in wind speed, a similar technique is being developed in which the ratio of wind speeds replaces the difference in direction. However, such errors, which seem to be caused by incorrect adjustment of the instrument rather than by a mechanical fault, are too infrequent to have permitted any detailed testing so far.

551.509.313

The lower boundary condition in the 10 level model

By A. J. Gadd

(Meteorological Office, Bracknell)

Summary

A new way of applying the lower boundary condition in pressure co-ordinate numerical models of the atmosphere is described. An indication is given of the benefits of the new method for the operational 10 level forecast model.

1. Introduction

The use of pressure (p) as the vertical co-ordinate in numerical models of the atmosphere is attractive in view of the simple form which the governing equations then take. The Meteorological Office 10 level numerical model, first described by Bushby and Timpson (1967), is a pressure co-ordinate model and in it the heights (h) and the horizontal velocity vectors ($\boldsymbol{V}$) are arranged on the 10 isobaric surfaces 100, 200, 300 . . . . . 1000 mb as shown in Figure 1.

The major disadvantage of the pressure co-ordinate system is of course the fact that the earth's surface cannot coincide with a co-ordinate surface; indeed it does not even remain fixed in the co-ordinate space. For this reason the sigma (σ) co-ordinate system (Phillips 1957), which uses pressure divided by the pressure (p_*) at the earth's surface (i.e. $\sigma = p/p_*$) as the vertical co-ordinate, has been widely used in other numerical models. This paper describes a method of representing the true position of the earth's surface in hydrostatic pressure co-ordinate models. Some general relationships are derived in section 2, and the application of these to the 10 level model is described in sections 3 and 4. The method has been used operationally in the octagon version of the 10 level model since 14 March 1978 and in the rectangle version since 4 April 1978 (see Burridge and Gadd, 1977, for a definition of the octagon and rectangle grids). Section 5 of this paper indicates some benefits of the new method for the model.

The kinematic lower boundary condition required in dynamical models of the atmosphere expresses the fact that the air flow cannot cross the earth's surface below. The condition may be written

$$w = \boldsymbol{V}.\nabla H \text{ at } p = p_*, \quad \ldots \quad (1)$$

where w is the vertical velocity, $\boldsymbol{V}$ is the horizontal velocity vector, and H is the topographic height ($H = 0$ over the sea). By definition, w is the rate of change of h following the motion.

$$w \equiv \mathrm{D}h/\mathrm{D}t. \quad \ldots \quad (2)$$

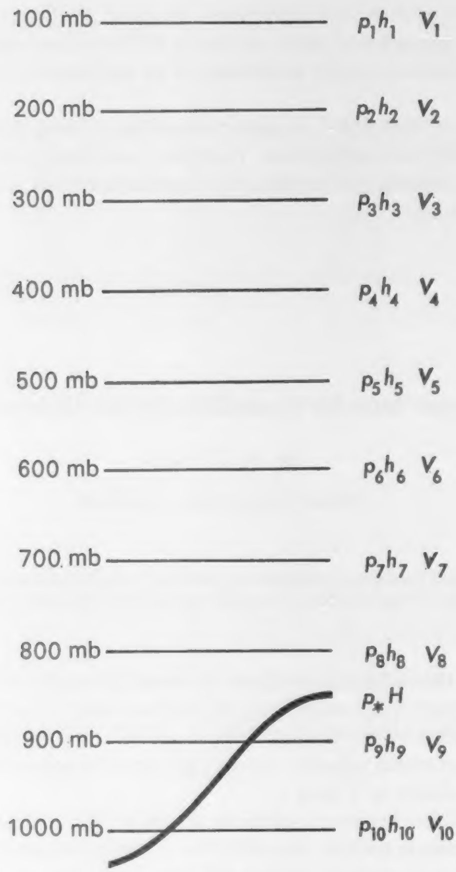

Figure 1. The vertical arrangement of heights (h) and wind vectors ($\boldsymbol{V}$) in the 10 level model, with an illustration of the earth's surface intersecting the co-ordinate surfaces. The earth's surface has pressure p_* and height H.

Earlier versions of the 10 level model, in common with most pressure co-ordinate models, used a lower boundary condition derived by setting $w = \boldsymbol{V}.\nabla H$ at the 1000 mb surface. Making use also of equation (2) this leads to

$$\mathrm{D}h_{10}/\mathrm{D}t = \boldsymbol{V}_{10}.\nabla H, \quad \ldots \quad (3)$$

where the subscript 10 indicates the 1000 mb surface as in Figure 1. Equation (3) is a predictive equation for h_{10}, i.e. the 1000 mb height tendency equation.

The application of the lower boundary condition at 1000 mb rather than at p_* seems a very crude approximation, especially over high mountains. However, equation (3) proved to be surprisingly effective in the 10 level model, for example in steering depressions to one or the other side of Greenland.

It was only when the effects of radiative exchange were included in the model that the unsatisfactory character of equation (3) finally became clear, as illustrated in section 5.

Previous attempts to overcome the deficiencies of equation (3) have been reported by Hayes (1975) and by Gadd and Lunnon (1977). Hayes applied surface frictional effects at model levels close to p_* and set $\boldsymbol{V}$ zero in any entirely subterranean layers. Gadd and Lunnon adopted Hayes's scheme, and in addition replaced equation (3) by

$$\mathrm{D}h_{10}/\mathrm{D}t = \boldsymbol{V}_{10}\,.\,\nabla H - (h_{10} - H)\,\mathrm{div}\,\boldsymbol{V}_{10}. \qquad \text{(4)}$$

The Gadd and Lunnon scheme achieved the benefits illustrated in section 5 below, but unfortunately led to numerical instability on some occasions. Thus the method described in this paper, which may be seen as a natural extension of Hayes's work, was developed as a more fundamental remedy to the inadequacies of equation (3). The idea of setting $\boldsymbol{V}$ zero in subterranean layers is due to Egger (1972).

2. Basic relationships

(a) The surface pressure tendency equation

The continuity equation in pressure co-ordinates for a hydrostatic atmosphere

$$\partial\omega/\partial p = -\,\mathrm{div}\,\boldsymbol{V}$$

may be integrated with respect to pressure to obtain

$$\omega_* = -\int_0^{p_*} \mathrm{div}\,\boldsymbol{V}\,\mathrm{d}p, \qquad \text{(5)}$$

where the subscript $*$ indicates a value at the earth's surface and $\omega \equiv \mathrm{D}p/\mathrm{D}t$. (The upper boundary condition $\omega = 0$ at $p = 0$ has been assumed.) By definition

$$\omega_* = \partial p_*/\partial t + \boldsymbol{V}_*\,.\,(\nabla_z p)_* + w_*\,(\partial p/\partial z)_* \qquad \text{(6)}$$

where ∇_z indicates the grad operator at constant z. If we substitute for w_* using the lower boundary condition, equation (1), we obtain

$$\omega_* = \partial p_*/\partial t + \boldsymbol{V}_*\,.\,[(\nabla_z p)_* + (\partial p/\partial z)_*\nabla H]. \qquad \text{(7)}$$

By a standard result in partial differentiation, the quantity in square brackets is precisely ∇p_* and therefore equation 7 gives

$$\partial p_*/\partial t = \omega_* - \boldsymbol{V}_*\,.\,\nabla p_*. \qquad \text{(8)}$$

Finally, recalling the general theorem that

$$\frac{\partial}{\partial x}\int_0^{L(x)} f(x,y)\,\mathrm{d}y = \int_0^{L(x)} (\partial f/\partial x)\mathrm{d}y + f(x, L)\,(\partial L/\partial x),$$

we may combine equations (5) and (8) to give

$$\partial p_*/\partial t = -\,\mathrm{div}\left[\int_0^{p_*} \boldsymbol{V}\,\mathrm{d}p\right]. \qquad \text{(9)}$$

Equation (9) is the basis of the method described in this paper. It represents the fact that, in a hydrostatic atmosphere, changes in ground-level pressure are the result of convergence or divergence of the vertically integrated mass flow above. The equation takes a similar form in the sigma co-ordinate system but the limit of integration is then a constant ($\sigma = 1$) so that the calculus is simpler.

(b) *Reduction to 1000 mb height tendency*

Several ways can be envisaged in which equation (9) might be used in practice in a pressure co-ordinate model. The method adopted here involves a conversion of the surface pressure tendency given by equation (9) to a 1000 mb height tendency. Like the reduction of surface pressure observations to mean sea level this conversion requires, in elevated land areas, an assumption about the temperature of imaginary subterranean air. If we assume that the (possibly fictitious) layer of air from the earth's surface (p_*) to the 1000 mb level (p_{10}) is characterized by a virtual temperature T_0, it follows from an integration of the hydrostatic equation that

$$\log_e(p_{10}/p_*) = g(H - h_{10})/RT_0 \qquad \text{.. .. .. ..} \quad (10)$$

and, neglecting any time dependence of T_0, that

$$\partial h_{10}/\partial t = (RT_0/gp_*)\, \partial p_*/\partial t. \qquad \text{.. .. ..} \quad (11)$$

The neglect of any time dependence of T_0 in deriving equation (11) is consistent with the method of reduction of surface pressure to mean sea level which is recommended in *WMO Technical Note* No. 61. There it is suggested that the temperature used should be based on the average of the current value of the surface air temperature and the value 12 hours previously, thereby eliminating the diurnal variation. In practice several different methods of reduction are in use by various nations (see *WMO Technical Note* No. 91).

Provided that T_0 can be specified, equation (11) can be used along with equation (9) to give the 1000 mb height tendency. However, the choice of T_0 is not without difficulty. In fact, a two-stage conversion process has been considered more satisfactory. In the first stage the surface pressure tendency is reduced to a mean sea level pressure tendency, and in the second stage the mean sea level pressure tendency is related to the 1000 mb height tendency. We assume that the fictitious layer of air from the surface (p_*) to mean sea level (p_{msl}) is characterized by a virtual temperature T_1 and the layer from mean sea level to the 1000 mb level (p_{10}) by a virtual temperature T_2. Then in place of equation (10) we have

$$\log_e (p_{\mathrm{msl}}/p_*) = gH/RT_1 \text{ and } \log_e(p_{10}/p_{\mathrm{msl}}) = -\, gh_{10}/RT_2. \qquad \text{.. .. ..} \quad (12)$$

Neglecting any time dependence of T_1 or T_2 these equations lead to

$$\partial p_{\mathrm{msl}}/\partial t = (p_{\mathrm{msl}}/p_*)\, \partial p_*/\partial t \text{ and } \partial h_{10}/\partial t = (RT_2/gp_{\mathrm{msl}})\, \partial p_{\mathrm{msl}}/\partial t. \qquad \text{..} \quad (13)$$

If T_2 is taken to be the temperature at mean sea level these equations may be combined in the form

$$\frac{\partial h_{10}}{\partial t} = -\left(\frac{\partial h}{\partial p}\right)_{\mathrm{msl}} \frac{p_{\mathrm{msl}}}{p_*} \frac{\partial p_*}{\partial t}. \qquad \text{.. .. .. ..} \quad (14)$$

The advantage of the two-stage conversion, leading to equation (14), over the direct conversion, represented by equation (11), is that it can avoid any troublesome complications over high ground whilst retaining a realistic temperature dependence over the sea and over low ground. This is achieved by keeping T_1, and thus p_{msl}/p_*, fixed at each grid point throughout a forecast whilst allowing T_2, by way of $(\partial h/\partial p)_{\mathrm{msl}}$, to vary in accord with the lowest available model information.

3. Application to the 10 level model

For the 10 level model equations (9) and (14) are used to give the required value of $\partial h_{10}/\partial t$ and this calculation replaces equation (4) of Gadd (1978). The other model equations and methods remain as described in that paper. The configuration of the variables used in this section is illustrated by Figure 2.

The following numerical approximation is used for the integral in equation (9)

$$\int_0^{p_*} \boldsymbol{V}\,\mathrm{d}p = \sum_{l=1}^{m-1} \boldsymbol{V}_l\,\Delta p + \boldsymbol{V}_m\,(p_* - p_{m-\frac{1}{2}}), \quad \ldots \quad (15)$$

where m is defined such that $p_{m-\frac{1}{2}} < p_* < p_{m+\frac{1}{2}}$. Each velocity $\boldsymbol{V}_l$ represents a 100 mb layer from $p_{l-\frac{1}{2}}$ to $p_{l+\frac{1}{2}}$ where $p_{l+\frac{1}{2}} = (l + \frac{1}{2})\,\Delta p$ and $\Delta p = 100$ mb. Equation (15) contains no contribution from above the 50 mb level, consistent with the 10 level model upper boundary condition $\omega = 0$ at 50 mb. Note that when $i < m$ the velocity $\boldsymbol{V}_i$ is given the full weighting Δp. However, $\boldsymbol{V}_m$ is given the reduced weighting p_*-$p_{m-\frac{1}{2}}$, whilst if $i > m$, $\boldsymbol{V}_i$ does not enter the calculation at all. Note also that the level m may be below the ground (as in Figure 2(*b*)), but some part of the 100 mb layer represented by $\boldsymbol{V}_m$ is always above the ground.

The following method is used to calculate p_*:

$$p_* = \begin{cases} p_l + \Delta p\,(h_l - H)/(h_l - h_{l+1}) & \text{if } H > h_{10} \\ p_{10} + \Delta p\,(h_{10} - H)/(h_9 - h_{10}) & \text{if } H < h_{10} \end{cases}, \quad \ldots \quad (16)$$

where $h_{l+1} < H \leqslant h_l$. At present equation (16) is used directly each time step; an alternative would be to use it only to calculate p_* from the initial data, and then to update p_* each time step using the tendencies given by equation (9). Equations (9) and (14) are applied at the h gridpoints in the 10 level model, and since equation (15) clearly must be applied at $\boldsymbol{V}$ gridpoints it is the four point average $\overline{p}^{xy}$ that is used. (See Gadd (1978) for details of the staggered grid now used in the 10 level model and for an explanation of the notation $\overline{}^{xy}$.)

The ratio p_{msl}/p_* is calculated at each gridpoint from the initial data and is then held constant throughout the forecast for use in equation (14). For the initial calculation p_* is obtained using equation (16) and the following equation is used to calculate p_{msl}.

$$p_{\mathrm{msl}} = p_{10} + \Delta p\; h_{10}/(h_9 - h_{10}). \quad \ldots \quad (17)$$

Finally, the value of $\partial h/\partial p$ required in equation (14) is approximated by

$$(\partial h/\partial p)_{\mathrm{msl}} = (h_{10} - h_9)/\Delta p. \quad \ldots \quad (18)$$

4. Note on the friction layer

This part of the formulation is adapted directly from Hayes (1975), and is presented again here for completeness.

The velocity at level l, the lowest level above the earth's surface, is modified by friction according to the equation

$$\partial \boldsymbol{V}/\partial t = -\,g\,\partial\tau/\partial p. \quad \ldots \quad (19)$$

It is assumed that the friction layer, adjacent to the earth's surface, is 100 mb deep, and that within this layer the stress (τ) is given by

$$\tau(p) = \{(p - p_* + \Delta p)/\Delta p\}^2 \tau_*. \quad \ldots \quad (20)$$

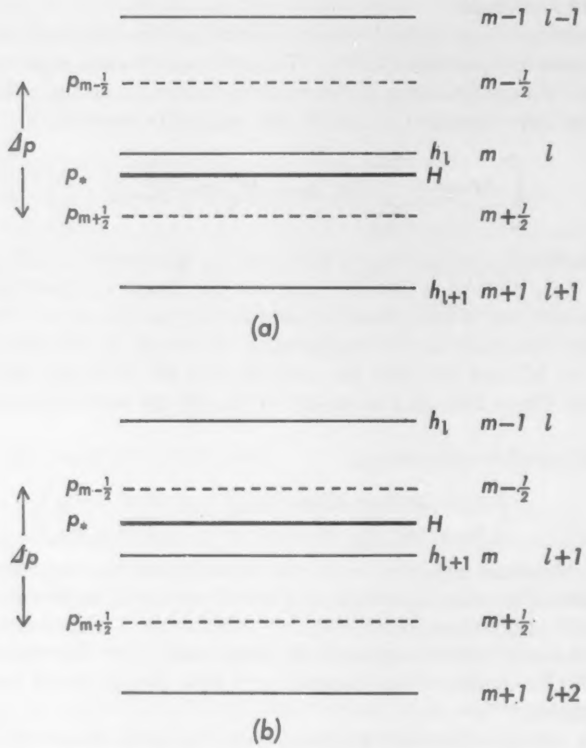

Figure 2. The 10 level model variables used in the calculations described in section 3. The solid lines correspond to levels shown in Figure 1. Two different configurations can arise, (*a*) $m = l$ and (*b*) $m = l + 1$, depending on the position of the earth's surface relative to the model's levels.

Thus $\partial\tau/\partial p$ at level l decreases linearly from $2\tau_*/\Delta p$ when $p_* = p_l$ to zero when $p_* = p_l + \Delta p = p_{l+1}$. The surface value of the stress as calculated from

$$\tau_* = \rho_l C_D |\boldsymbol{V}_l| \boldsymbol{V}_l, \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (21)$$

where ρ_l is a standard atmosphere density and the drag coefficient (C_D) is 10^{-3} over the sea and 4×10^{-3} over land. Although level $l + 1$ is below the ground, $\boldsymbol{V}_{l+1}$ may be required for equation (15), as in the configuration shown in Figure 2(*b*). Frictional effects are applied at level $l + 1$ with $\partial\tau/\partial p$ always calculated as $2\,\rho_{l+1} C_D |\boldsymbol{V}_{l+1}| \boldsymbol{V}_{l+1}/\Delta p$. For any $i > l + 1$, $\boldsymbol{V}_i$ is set to zero. The frictional formulation is such that the numerical method given by equation (20) of Gadd (1978) may still be used.

5. Effect on 10 level model forecasts

Equation (3) was used as the lower boundary condition of the 10 level model for many years, and it was not until representations of the effects of radiative exchange were included in the model that the requirement for some improved lower boundary condition became unmistakably evident. For output purposes h_{10} is converted to p_{msl}, and the mean values of p_{msl} for the whole model area, denoted by $\overline{p_{\mathrm{msl}}}$, are used in Figure 3 to illustrate model behaviour. Figure 3 shows the evolution of $\overline{p_{\mathrm{msl}}}$ during three different six day octagon forecasts for each of two cases. The three forecasts are labelled A, B and C as follows:

A: The model used equation (3) but did not include the radiation scheme.

B: The model used equation (3) and included the radiation scheme.

C: The model used equations (9) and (14) and included the radiation scheme.

Considering first forecasts A and B we see that $\overline{p_{\mathrm{msl}}}$ changes significantly during the integrations. In both cases the inclusion of the radiation scheme leads to higher values of $\overline{p_{\mathrm{msl}}}$. In case (a) this increase offsets the loss of pressure seen in forecast A, but in case (b) the increase adds to an already existing gain of pressure. It was in cases of the latter type that the forecast charts produced were very obviously unrealistic.

The results of forecasts A and B may be explained as follows.

By expanding the total derivative in equation (3), rearranging terms, and meaning over the whole octagon area, we obtain

$$\overline{\partial h_{10}/\partial t} = -\ \overline{\omega_{10}\,(\partial h/\partial p)_{10}} - \overline{\mathrm{div}\,(h_{10}-H)\boldsymbol{V}_{10}} + \overline{h_{10}\mathrm{div}\boldsymbol{V}_{10}} - \overline{H\mathrm{div}\boldsymbol{V}_{10}}. \qquad \ldots \quad \ldots \quad (22)$$

The first term on the right of equation (22) is unlikely to be large whilst the second term, being in a divergence form, reduces to an effect of flow across the lateral boundaries. The third term, however, is likely to have a systematic positive bias as a result of the natural correlation of high surface pressure and low-level divergence. The effect of the final term may also be large but its sign and magnitude will depend on the configuration of high and low pressure systems with respect to topographic features.

Equation (22) shows that equation (3) places no constraint on the spatially averaged value of h_{10}. Even in a global model the third and fourth terms could lead to large changes in $\overline{h_{10}}$, and since h_{10} is representative of the surface pressure, one might say that a model using equation (3) does not conserve the mass of the atmosphere.

When the radiation scheme is included in the model, high and low pressure systems retain realistic intensities throughout six day forecasts. (Without radiation there is a gradual loss in the amplitude of features.) Thus the inclusion of radiation increases the value of $\overline{h_{10}\mathrm{div}\,\boldsymbol{V}_{10}}$ and this accounts for the higher values of $\overline{p_{\mathrm{msl}}}$ produced by forecast B.

By contrast with equation (3), the form of equation (9) ensures that the mean value of p_* in any region changes only as a result of fluxes across the boundary of the region. Mass conservation is directly represented and in a global model $\overline{\partial p_*/\partial t} = 0$. The constraint imposed by equation (9) is evidently quite effective for the octagon area average of $\overline{p_*}$, and this is reflected in the slowly changing values of $\overline{p_{\mathrm{msl}}}$ produced by forecast C as shown in Figure 3.

The formulation described in this paper is of direct benefit to the 10 level model in that it gives a more accurate representation of the true lower boundary condition. It has also had the indirect benefit of making possible the inclusion of the radiation scheme. The annual average root mean square forecast errors for 1978 were the smallest since numerical forecasting began. It is likely that this may be explained by the combined benefits of the radiation scheme and the improved boundary condition.

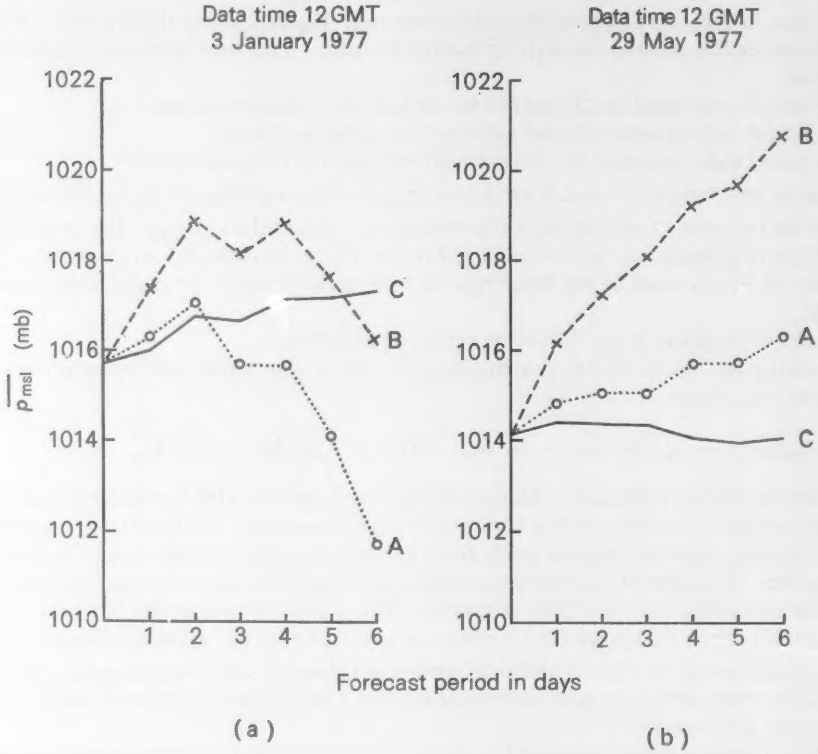

Figure 3. The forecast evolution of $\overline{p_{\text{msl}}}$ (see section 5) for the whole octagon grid for (a) a winter case and (b) a summer case. The three forecast model formulations A, B and C are identified in the text.

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Memoirs of an Army Meteorologist

By H. Cotton, M.B.E., D.Sc.

Part 2

My first duty assignment was to a double-observer station close to Sailly Labourse. This I found to be a drab, sizable village about four miles south of Béthune on the road to Arras. As there was no transport available I had to go by train to Béthune and then walk. The pitiful inadequacy of the French railway system was obvious. I actually found myself back at St Omer, then Hazebrouck, Lillers and finally Béthune, which I reached in the middle of the afternoon. If the Germans could have destroyed the railway system at and around Abbeville they would have gained a victory of enormous strategic importance —perhaps have brought the war to an end.

The two Meteor observers were attached to the 15th Division Headquarters in the imposing Château of Sailly Labourse. The 15th was an all Scottish Division which had been in action at the Battle of Loos, a few miles to the south, had fought with the courage characteristic of the Scots, and had suffered very heavy casualties, a waste of splendid men.

Our billet was a very large room at the top of the Château, obviously a bedroom for the staff in former days. It had two real beds and was indeed luxurious for wartime conditions. Close to the window was a large tree inhabited by little animals of a kind that I had never seen before. They were squirrel-like but smaller, their long tails bare except for a bush at the end, something like a miniature lion's tail. I made a little box for food which I suspended from the branch near the window and they used to queue up. The animal actually feeding would receive a nip from the next in the queue if it kept the others waiting too long.

My fellow observer was Corporal George, an artist who had served in the Artists' Rifles; although now officially an R.E., he retained the very distinctive Artists' Rifles cap badge, no doubt a kind of snobbishness. Actually the Artists' Rifles Regiment was kept so long at G.H.Q. that they came to be known as Haig's darlings. They had to be meticulously turned out. Not unnaturally there was a little resentment on the part of the troops who were doing all the dirty work and who were by no means so meticulously turned out.

Corporal George was given to introspection and was, in consequence, difficult to talk to at times. I was curious to learn how an artist had come to join the Meteorological Section and one day I asked him, receiving a characteristic reply:

'What was the first thing they asked you when you reported to the R.E. barracks in England?'

'Where the hell have you been all this time, or something like that.'

'Precisely, and if I were as stupid as the average warrant officer appears to be I should have said the same. The fact is that after the fiasco at Loos, it was obvious to everybody, even the brass hats at the War Office, that if we were to continue with the use of gas we must have up-to-date information about the local weather, particularly about the wind over the whole of the intended battle area. That meant a new organization including an ample number of observers, and as they couldn't wait for men like you to come out they had to make do first of all with what they could find on the spot.'

'Yes, I realize that, but, I hope you won't take offence at this, why did they choose an artist like you?'

'I haven't the least idea unless they thought that since an artist's job is to observe things he ought to be able to observe the weather. Now, will you tell me something?'

'Yes,' I said 'If I can.'

'Meteorology is a science, and science, so I have been told, is exact knowledge. But Meteorology is anything but exact—look at what happened at Loos, and think of all the weather forecasts which, all too frequently, are completely wrong.'

'That is a difficult question' I said 'and can only be answered at length.'

'All right, carry on.'

'It will be something like a lecture.' (This reply made in early 1916 is relevant even today.) 'The Laws of Science are founded on the results of experiments carried out under precisely specified conditions not once, but many times. They are substantiated by the fact that predicted results can be obtained over and over again, millions of times, at schools and universities all over the world. For example Faraday's Laws of Electrolysis predict the weight of a given metal that will be deposited on the cathode of an electrolytic tank by the passage of a stated quantity of electricity. I could give you many other examples. These and all other predictions which come within the realm of experimental science result from experiments made on manageable amounts of the substances concerned. Even Aristotle said that the principles of science are the result of experience. But you can't put a bit of the weather on a laboratory bench, dissect it, weigh it, boil it in a test tube or do any other of those manipulations appropriate to scientific research. With the weather it is impossible to vary at will one of the factors while maintaining the others constant. Just consider how many variables there are: barometric pressure, wind velocity and direction, temperature, humidity, all dependent on one another, but nobody knows just how and, in my opinion, never will. The best that can be done is to collect as much information as possible from as many widely spaced observations as possible, and—this is a most vital condition—all these observations must be made at exactly the same moment. There are four what are called fundamental hours, namely 1 and 7 a.m. and 1 and 6 p.m., all GMT. These are recognized the world over. From this mass of information the weather charts, synoptic charts as they are called, can be drawn and the probable weather for the next twenty-four hours or so predicted with more or less accuracy according to the nature of the chart. In very awkward cases it may be necessary to refer back to previous charts and the corresponding forecasts until one as nearly as possible to the current chart has been found. This is not very satisfactory as there are never two charts exactly alike, and quite small differences can result in astonishing differences in the weather pattern. This is another way of saying that local weather is only a microscopic part of the global distribution and furthermore that this global distribution is three-dimensional, not two-dimensional. I have not seen the chart for the day of the Loos battle, but I am quite sure that there would be no indication whatever of the change in wind which brought such tragic results.'

I was to experience this in the early spring of 1917 when, out of a serene blue sky, there suddenly erupted a storm of tropical violence accompanied by hailstones as large as goose eggs, but jagged. The storm was over in minutes and covered only a small area. It was probably due to temperature changes and could not possibly have been predicted.

'Quite a lecture, as you said. Obviously I criticized too soon. And now' Corporal George said 'I will tell you something you will be advised always to remember. They should have informed you at G.H.Q. so stop me if they have. We are not ordinary troops belonging to a regiment and never separated from it. We are, in a way, freaks, lone rangers. We are G.H.Q. troops, our Headquarters and our O.C. being at G.H.Q. Consequently, we are not subject to discipline by anybody outside G.H.Q. no matter who they are. So if you get into trouble with anybody, although I don't think it likely with you—'

'Thanks' I said.

'just tell them that you are a G.H.Q. troop and that if they wish to bring a charge against you it will be necessary for them to refer it to G.H.Q. since there must not, under any circumstances, be any interference with the observations you have to make and the time you make them. In many cases they won't

like it but, if the need arises, and you never know in the army, just keep your nerve.' On more than one occasion I was to be grateful for that advice.

The observation post was about two hundred yards east of the Château close to an abandoned trench system. The ground was fairly level although rough, and after about one hundred yards further east it descended gently to the Béthune–Lens road. There were no obstacles to interfere with the true flow of the wind and the site was therefore about as good as could be found in the neighbourhood. Sailly Labourse was at the northerly edge of the Lens coalfield and I experienced again the impression of the sadness of the countryside adjacent to a mining district. The site was dominated by a very large colliery spoil heap, the Annequin Fosse, occupied by the enemy, of course, and giving perfect observation for miles around. When making observations I always had a feeling that I was being watched, even at 1 a.m., because I had to use a torch in order to manipulate the anemometer and read the thermometers.

I found it very strange and, in a way, very exciting, the realization that, at the fundamental hours, thousands of observers all over the world were performing manipulations identical to those I also was making.

Close by, but not enemy-occupied, were the small towns of Vermelles and Noeux-les-Mines. These were frequently shelled and occasionally salvos would fall close to the Château. It was said that there was a gentleman's agreement about shelling one another's Headquarters, although a six-inch high-explosive shell once wrecked the cookhouse. Perhaps this was a mistake. After the commencement of the Somme battles, when the Germans realized that the British really meant business, even although the balance sheet was a disaster, this agreement was dropped and the shelling of Headquarters became the norm.

One morning about half an hour before setting out to make the 7 a.m. observations I heard a salvo of shells coming over and they seemed to be close to. I only paid attention to them because the sound of their flight was different from anything I had heard before, and they did not seem to explode with the usual violence. On the way to the observation post I noticed about fifty yards away a patch of fog. Apart from the fact that the current weather type was not one associated with fogs, the area covered seemed to be very small. As it was unusual I decided to mention it in the weather diary and then thought no more about it. While I was making my observations the cloud had drifted across the path and it was not a meteorological cloud as I had thought but lachrymatory gas and I had not brought my protective goggles. I think I cried all the day and I was careful not to be caught again. Fortunately I always made out my telegram forms before returning to the Château so it was not necessary to grope my way upstairs and ask Corporal George to do them for me.

In all wars and to all arms, except perhaps the P.B.I., there are moments of sheer farce. I experienced a few. When it was my week to make the daytime observations my afternoons were free because the 3 p.m. results were not sent off straight away but were added to the end of the vitally important 6 p.m. telegrams.

On the far side of the Lens road there was a stream, according to the map designated by the description Courant de Bully. I decided to explore it. From an early age I had been fascinated by the creatures that lived in fresh water, not merely redpinks, and I cannot even now resist the temptation to examine any likely looking ponds. A pond is a little world of its own, ecologically self-sufficient and therefore fascinating to anyone who will take the trouble to study it.

On the Lens road there was an isolated estaminet, and after pond gazing I sometimes went in for a drink. It is probable that this was within prohibited hours, for the killjoy hand of Mrs Grundy reached out even to troops, many of whom would never go home again. If this was the case the young woman who served me was unconcerned; after all the French had no equivalent of Mrs Grundy so, as far as she

was concerned, she was not breaking any law. I called mainly because it was a good chance to converse in French thereby improving my facility with the language. I was not aware that I was regarded as a suspicious person until, one afternoon, I found not the young woman, but an M.P.

'Good afternoon' I said.

'Good afternoon, I want to talk to you.'

'Well, I want a drink, where is m'selle? Are you serving the drinks today?'

'Don't try to be funny. What are you doing here anyway?'

'It's obvious isn't it: as I have just said I have come for a drink.'

'You won't see m'selle as you call her again. She is a spy and will most probably be shot.'

'Good God!' I exclaimed horrified 'I used to have quite long conversations with her, but I certainly never dreamed of anything like that. You are not pulling my leg are you? Are you quite sure?'

'Of course I'm sure. So you speak the lingo. That accounts for it.'

'Accounts for what?' I demanded, suddenly realizing what he was driving at.

'Well, who the hell are you. I have watched you for some time and for a mere corporal you seem to have a lot of time on your hands. You are an R.E., I see. Who is your commanding officer and where is your unit? I don't know of any R.E. Company being stationed anywhere near here.'

So that was it. How many more times would I have to explain the peculiarities of my role to some unbelieving person?

'My headquarters is at G.H.Q. I am a G.H.Q. troop.'

'Never heard of 'em.'

'Well, you are looking at one now.'

'All right, tell me what you do.'

'Now *you* are asking about secret information, perhaps you ought to be shot.'

'Well I'm buggered.'

'That is your own personal affair' I said nastily. I was becoming annoyed and also apprehensive. It was decidedly uncomfortable to be mixed up with spying even although one was innocent.

'Look' I said 'I am attached to 15th Division Headquarters, although I am not on the Divisional Staff. I think the best thing will be for you to come with me to the Château and I will take you to Signals. My work involves sending frequent telegrams, priority telegrams, to G.H.Q. and various Headquarters. The signallers know me and will vouch for me. If that does not satisfy you then I will take you to the General.'

'You can't do that. Who ever heard of a mere corporal going to a General?'

'Stop calling me a mere corporal. Perhaps it will interest you to know that I spoke to the General only this morning.' That was true as he had stopped and asked me what the 'glass' was doing while I was reading the barometer. 'As you must know there is always the possibility of reaching someone of high rank by starting at the bottom of the ladder and working upwards.'

'All right, I'll take your word for it although I have never seen any of your kind before. Anyway don't come here again.'

'There's not much point is there' I said 'if I can't have a drink. Still I can come for a pleasant walk unless the area is out of bounds, which it isn't as far as I know.'

Thinking about the incident later on I wondered if it had been a ruse on the part of the M.P. to find out what I was doing without asking directly and receiving a dusty answer. Certainly a soldier, not commissioned, wandering about apparently at will must have been a strange phenomenon, and his suspicions must have been increased by the fact that there was a battery of field guns only a little further along from the pond. I did not know about it because I had never heard it in action, but the M.P. might reasonably have believed that I had seen it. Certainly I should have found him out—if I had not been

transferred the next day to another area—but by his ruse. If it was a ruse, he would have found out that I was harmless. On the other hand he might have been telling the truth as there was a considerable amount of the collecting of information by unwary troops and passing it on to the enemy. Such people were particularly keen on obtaining information about troop movements and attractive girls in estaminets were obviously the most successful enemy agents.

Le Touret is a village a few miles north-east of Béthune. I will describe it as I knew it. It straggles along the downward-sloping road to Laventie where there was bitter fighting during the first year of the war. Like nearly all the French villages I knew it had no pretence to beauty whatever but the surrounding countryside is pleasant. To the north-east, across the Canal d'Aire and a branch which links up with the River Lys is a large wood which was to provide recreational facilities in a few weeks' time. At the top of the road to Laventie, that is to say at the western extremity of the village, there is a large farm of typical Artois construction: an open rectangle having the farmhouse itself as the joining member to two wings, one comprising store-rooms and the other sheds for the animals. In the middle is the inevitable large midden, a paradise for flies and rats. The neighbouring village of Loisne is about half a mile to the south but by road it is a very long way away. The direct route is along a water-filled dyke with many willow trees, some of them appearing to be very old. The delightful demoiselle dragon-flies, some blue, some pale green, flit ceaselessly to and fro over the water and frequently they fly joined together in tandem for the purpose of their aerial lovemaking. There is no sign of the ugly complex of mining towns, Noeux-les-Mines, Vermelles, Mozingarbe and Loos of tragic memory, although these are only a few miles away.

Opposite the farm lands bordered by the south side of the Laventie road are two fields, one on either side of the dyke. In a corner of the field to the west is my observation post, consisting simply of a pole having fixed at the top, five feet from the ground, a square brass plate marked with the compass points and correctly oriented. At the centre of the plate is a pin to take the delicate anemometer. There is also a Stevenson screen, a small louvered cupboard, also about five feet from the ground, and containing dry and wet bulb thermometers. Wind and temperatures are the only measurements made at a single-observer station, but cloud kinds and amounts and estimates of heights have to be recorded in the weather diary. In particular it is necessary to be vigilant when the wind is in a quarter which is dangerous from the point of view of enemy gas attacks. The field to the east of the dyke is very extensive, falling away gently to the very confines of the village. At the top corner, adjacent to the road, there is a strong-point dug into the ground. It has a ten yard protective belt of barbed wire, the lowest strands being not more than a foot from the ground, and all arranged, not haphazardly as is usually the case, but to an intricate geometrical design which ensures that there are no gaps. No creature other than an animal small enough to crawl underneath can get through. Owing to the slope of the land there is an ideal field of fire except along the road where the perspective effect of trees growing close together along the roadside gives an unbroken barrier unless an attack delivered up the road reaches almost to the strong-point. The wire entanglements are so perfectly constructed as to give the impression of an exercise in fortification. If so, it was no doubt assumed that flank support would be provided by fortifying the farm buildings, and eventually this proved to be the case.

I was brought to Le Touret to take the place of a man who was going on leave. The farm was a Headquarters of an R.E. Company, the officers billeted in the farmhouse while the men occupied wooden hutments ranged round three sides of a field. A corner room in the yard was used as the orderly room. I had a hut to myself just off the road to the village. I was attached to the Company for rations, shelter and pay, but not for discipline, this being the concern of Meteor G.H.Q., since I was a G.H.Q. troop. I am afraid I was apt to flog this somewhat since it is human nature to make the most of circumstances which act to one's advantage. Apart from the necessity of carrying out the observations and sending the

telegrams in code to a prescribed set of addresses, I was on my own and could occupy my spare time as I liked. I made many sketches of the least unlovely parts of the village, having abandoned further attempts at the human form divine, and gave them to the troops. [In an intervening section of his Memoirs Dr Cotton recalls that he became adept at producing sketches of nubile maidens by drawing on his imagination.] As there were no picture-postcards of Le Touret these were very popular and could have occupied most of my spare time.

Because I was, to all intents and purposes, on my own in a world where the life of everyone was strictly regulated, the position of the Meteor observers had been explained previously to the commanders of all units to which observers were attached and as a result I experienced no trouble. What was overlooked at Le Touret was the necessity to explain my presence to an incoming company if and when a change-over took place. When it did take place I expected that everything would be the same as before. When one such change-over took place the departing Company left at mid-morning but the relieving Company did not arrive until late afternoon. I made good use of this freedom of the camp to 'win' a number of very useful articles: a small 'coffin and flower-pot' stove which fitted very nicely into one corner of my hut, wood and wire netting with which I constructed a very comfortable bunk much superior to sleeping on the floor, a supply of coal which I stored under the bunk, and various odds and ends.

The new Company had arrived somewhat before the time of my 6 p.m. observations and when I went to the post at about ten minutes to the hour the place was full of people all milling around. The method of determining the wind direction was as follows: the anemometer was turned to such a position that the vane was stationary, the wind direction thus being along the plane of the vane. This direction was noted and entered on a special form CM 003; the anemometer was then turned through 180 degrees and the reading again taken. This observation was made three times so that altogether there were six observations, the mean being taken as the wind direction. The object of this procedure was to eliminate the effect of slight variation in direction. On this occasion the wind was in the most dangerous position, whereas it had not been even in the alert position when I made the 3 p.m. observation. Consequently, as no alert warning had been sent it was imperative to send the danger warnings immediately. I therefore abandoned for the time being the rest of the observations and hurried to the orderly room where the telephone was. The room was bare except for a long trestle table with a pile of papers. The O.C. of the new Company was seated at the middle and the R.S.M. at his side. Usually it would have been the orderly officer but as the Company had only just arrived he and the other commissioned officer were organizing the billeting, the officers in the farmhouse and the men in the hutments. There were two sappers standing at ease by the end wall and I was surprised to see that one of them was a student, Denton, from the St Helens days. He was equally surprised to see me.

I expected that everything would proceed exactly as before so I marched up to the O.C., saluted, and made the usual request:

'May I use the phone sir?'

'Who the bloody hell are you?'

'Meteor sir, I have a number of extremely urgent telegrams to send.'

'Well you can clear out and take your telegrams somewhere else. Who the hell are you anyway barging into my orderly room like this?'

Here we go again, I thought, I shall have to go through that rigmarole all over again. It is becoming monotonous. I tried to explain my position, realizing that this new man knew nothing about it.

'Sir' I said, 'it appears that my position has not been explained to you by the outgoing Company, this, of course, being impossible since they had departed before you arrived.'

'No it wasn't, and now will you get out or must I have you thrown out?'

'Keep your nerve' Corporal George had said and now was the time for it. Also for *l'audace*.

'I wouldn't advise that, sir, as you clearly do not know what authority I have' —'Blimey!' from the R.S.M.—'Surely you must realize by my interrupting your orderly business in this way that I possess the necessary authority. My telegrams are becoming more urgent with every second's delay. Will you please allow me to send my telegrams immediately and explain my position afterwards?'

He again threatened to have me thrown out so that I had no alternative but *l'audace*.

'Very well sir' I said 'somebody may get shot at dawn for this and I assure you it won't be me. There are witnesses.'

'Bloody hell' said the R.S.M.

The O.C., speechless by this time, waved his hand towards the phone, which was wall-mounted. I picked up the receiver and turned the handle.

'Is that Signals? I have a number of first priority telegrams . . . Who am I? Oh my God are you new as well? Is there an officer available? . . . Good, will you ask him to speak to me please, it is very urgent . . . Is that the Signals Officer? I am Meteor, I have a number of first priority telegrams to . . . What is my rank? What the hell has that to do with it? I am a corporal, but I belong to G.H.Q. . . . Look here, the wind has suddenly changed to the most dangerous direction, and if the Germans release gas now the men in the trenches won't stand a chance. The change of wind has been so sudden that it has not been possible to send a gas alert. As I said, I belong to G.H.Q., and I am acting with the authority of G.H.Q.'

Once again the R.S.M. muttered 'Blimey!' and I continued:

'You will take the message yourself. Thank you sir. First priority to Headquarters 40th, 50th, 51st and 55th Divisions. The message—Gas warning, wind at seventeen fifty five hours south esses by south ack ack ack. Signed Cotton, CO toc toc ON Le Touret LE Toc OURE toc.'

The two sappers grinned but straightened their faces on seeing the scowl on the O.C.'s face.

'Will you repeat that please? Thank you sir. I must now complete my observations after which I shall have more telegrams to send and this time in code. Priority but not first priority. Just one thing more sir. The gas warnings are to be sent to Meteor Second Army and to the Headquarters of the eleventh and fifteenth Corps, but these are for information only and are not priority. Thank you sir.' I replaced the receiver and turned to the O.C.

'You will have heard the conversation sir, at any rate my end of it and I am sure it will have made my position perfectly clear. I must now go and complete my observations. I had to interrupt them when I found that the wind had changed with unexpected suddenness to the most dangerous direction.'

'Yes, that is perfectly clear, but you will understand that I knew nothing about you. What I want to know is how you fit into my Company, what is your relationship to me?'

'I am attached to your Company for shelter, rations and pay.'

'What about discipline?'

'No sir. I belong to G.H.Q. as I had to explain to the Signals Officer and therefore in this respect I am not subject to you . . .'

'Blimey!' once more from the R.S.M.

'but if you have reason to believe that discipline is necessary, although I can hardly imagine it, I suggest that you contact Meteor Second Army. Alternatively since a D.R. (dispatch rider) from G.H.Q. calls on me once a week for my reports, you could give me a sealed letter addressed to my O.C., Colonel Gold, D.S.O. and I will include it with my material.'

'How many times during the day will you require to use my telephone?'

'Four times sir, 0-one hours, 0-seven hours, thirteen hours and eighteen hours, all GMT.'

'0-one hours, one o'clock in the morning. That means that the orderly room door will have to be unlocked.'

'That was the arrangement with the previous Company. There is one thing more. It was the rule for the sentry to waken me at 23.45 hours and I should be grateful if you will also arrange for this. And now I really must complete my observations. They should be made exactly at 18 hours, the exact time at which simultaneous observations are made all over the world.

'You have found yourself a nice cushy job' (sarcastic).

'There are many ways of doing one's duty sir.'

I then saluted and left. The remainder of the O.C.'s reaction I learned from Denton a few days later. The O.C. banged his fist on the table and shouted:

'Of all the bloody ridiculous nonsense, a mere corporal wished on me for rations and pay and actually having the bloody nerve to give me orders.'

Turning to the R.S.M. he asked 'What do you make of it?'

'I don't know what to make of it sir. I had no idea there were people like him in the Army. He certainly ticked you off, if you don't mind my saying so, and he certainly gave orders to the Signals Officer. And did you realize that he seemed to know the names and probably the locations of all the army units, information that even you do not possess. Authority of G.H.Q. is certainly a new one on me and I'm quite sure he wasn't bluffing. We shall have to put up with him I'm afraid. Still, I can't see that he will be any trouble.

'Yes, you are probably right'. The O.C. turned to the two men who both jumped to attention. 'Sapper Denton'.

'Sir.'

'You and this Meteor fellow seemed to recognize one another. Do you know him?'

'Yes sir,'

'Well, go on.'

'Before I joined up, sir, I was an engineering apprentice and I was sent to the technical school to take a part-time day course. Mr, er Corporal Cotton was one of my lecturers.'

'I see, it was a strange coincidence, what was his subject?'

'Electrical engineering and advanced Mathematics sir, although I was given to understand that he was a Physicist as well.'

'I suppose that accounts for it. All right, stand easy.' He turned to the R.S.M. 'We might as well transact *some* business before he comes and disturbs us again.'

'Yes sir.'

A day or so after this incident I was walking along the road in the direction of Béthune. The strong sun in a cloudless sky threw black shadows across the road, uniform like the rungs of a ladder. Sapper Denton was sitting by the roadside stripped to the waist, his tunic and shirt lying on the ground beside him. His vest was turned inside-out and he was diligently searching the seams, muttering angrily as he did so. Every now and then he pressed his thumb nails together and a sickening crack would indicate the end of one of those loathsome creatures which could make life a misery.

'Hello Denton, delousing? I think I will join you as I have a private menagerie of my own to attend to.'

'These bloody chats' Denton said 'wherever do they come from? We didn't have them in the training camps at home. They are enough to drive a fellow daft. Some of the chaps believe they come out of the ground because, they say, the Froggies are dirtier than we are.'

'If you go to the slums of any of our big cities you will soon find out that the French are no worse than we are. There are filthy people everywhere. No, it's the lack of civilized amenities. Very little water and the impossibility of getting a hot bath. Like you, I never saw a louse until I came here.'

'What about my O.C.?'

'Shh . . . if somebody hears you say that you'll most probably get a stint of pack drill.'

'Stint. Fancy hearing that word out here.'

'Yes, it appears to be associated largely with the mining industry. I never heard it until I went to teach in a mining community. How far away it all seems; the Technical School, the visits to industry like the glass works and the cable works at Prescot. Somehow I have a feeling that life is going to be very different when we get back.' 'There won't be any chats and that's something. Do you mind if I ask you something personal?'

'I will answer if I can. What is it?'

'The men have been very interested in you since the way you stood up to the Captain, especially as he is a holy terror and has a hell of a temper. They all wished they could have seen it. Another thing they want to know is how you got into your lot.'

'The only answer I can give to that is, unbelievably good fortune and the fact that I am a scientist doing a scientific job. But I cannot regard myself as a soldier. I am only a civilan in uniform.'

'Aren't we all?'

'It is not the same. I came out here with no military training whatever, no square bashing, no weapons training, and in spite of my corporal's stripes, if I was put in charge of a party of men I should have no idea what to do with them.' I little realized how prophetic that remark was to be. 'A few weeks ago somebody realized that I had been sent out without any weapons so I was issued with an enormous revolver which nearly knocked me down when I fired it. Perhaps it is because I regard myself as a civilian that I am not afraid of officers.'

We had no sooner finished dressing than there was the sound of gunfire.

'Damn!' I said.

'Why, what is it?'

'There must be a German plane about. Yes, there it is coming this way. The plane is nothing to worry about, not to us, it's the gunfire. The anti-aircraft guns are old R.H.A. twelve-pounders on make-shift mountings. They never hit anything because they can't follow quickly enough, but everything they send up has to come down, in the form of a vertical rain of shrapnel and shell fragments.'

'Ought we to lie down or something?'

'No, that is the worst thing to do. The explosions are high up in the sky, not at ground level like ordinary shelling. One way is to stand upright and make yourself as thin as possible so as to present the least possible target area, but that takes some nerve as it is contrary to all instinct. A tree affords as good a protection as anything. Come on' I said.

We ran across the road and stood with our backs to one of the trees, which were along one side only. The plane sailed on, apparently indifferent to its wake of little white puffs which, continually reaching out, never succeeded in catching up with it. Shrapnel began to fall, bringing leaves and twigs falling from the tree. With a crescendo of sound like the approach of a heavy goods train, an unfragmented shell body crashed on the place where we had been delousing.

'Blimey, no matter where you put your tin hat it wouldn't be much use against that.'

I returned to my hut and sat on my home-made deck-chair, another result of my successful scrounging expedition. 'How can one get into your lot?' Suddenly I realized that I must be one of the most fortunate men in the army and that, as the O.C. had said so nastily, I had found myself a cushy job. I knew by now something of what the P.B.I. had to put up with, and the worst was yet to come. Somehow it

didn't seem right, but I consoled myself with the knowledge that in contrast to my Army pay, there were many thousands at home, safe from danger and hardship and making fortunes out of the war.

(To be continued.)

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Review

Boundary layer climates, by T. R. Oke. 230 mm × 150 mm, pp. xiv + 372, *illus*. Methuen & Co. Ltd, Andover, Hampshire, 1978. Price £10.50 (University Paperback edition £7.50).

This book is intended as an introduction to the nature of the atmosphere near the ground for those who wish or need to know but are 'daunted by the technical nature of most micro- or biometeorological texts which assume a reasonably advanced ability in physics and mathematics'. The author reinforces this statement in the Preface by steering those with the appropriate scientific background towards more rigorous and complete expositions of the subject, in particular Geiger's now classic study 'The climate near the ground' (1965). To achieve his aims the author's discourse is of an explanatory rather than of a descriptive nature and is illustrative rather than comprehensive. The book is structured in three main parts and its scope is displayed clearly and in detail in the Contents.

Part I. Atmospheric systems comprises two chapters intended as a simple scientific introduction to atmospheric boundary-layer processes and to surface and soil properties and exchanges. Here the physical foundations are laid for the subsequent discussions of a wide range of surface environments. In accordance with the stated intention, mathematical equations have been kept to a minimum and the text is much more of a qualitative rather than quantitative nature. The reader is guided carefully and steadily through the essential basic concepts of the surface energy and water balances and is given insight into the character of subsurface climates and the role of the turbulent processes in the boundary layer. The uninitiated student who dwells on these two chapters long enough to master the apparent plethora of cumbersome symbols which are a guaranteed feature of any discussion of the fate of solar radiation entering the earth–atmosphere system and to absorb the physical principles discussed, will be amply rewarded in the following sections. Fortunately, the considerate author has made decipherment easy by providing a comprehensive list of symbols. Part I gives a generally good, clear and informative introduction to the book.

Part II. Natural atmospheric environments comprises four chapters on an extensive variety of natural surfaces and systems. There is a planned, gradual progression from relatively simple surfaces to more complex systems as one advances through Chapters 3–6 which concern the climates of simple non-vegetated surfaces (including sandy desert, snow, ice and water surfaces), vegetated surfaces, non-uniform terrain and animals, respectively. The spirit of the book is embodied in an interesting section on snow and ice in Chapter 3 where, for example, the wavelength dependence of the albedo of snow is invoked to help explain the ease with which skin becomes sunburnt and why earlobes, throat and nostrils, areas which are sensitive and normally in the shade, become particularly vulnerable on sunny days on snow-covered mountains.

After two further sound and informative Chapters, 4 and 5, the section culminates in *Chapter* 6, *Climates of animals*. Bearing very much in mind the author's intention to be illustrative rather than comprehensive, this is the chapter which the reviewer found most intriguing, absorbing and simply enjoyable to read. Natural historians and avid followers of David Attenborough's 'Life on Earth' start here! Because animals are able to move and carry their own internal energy supply (metabolic heat) they and their immediate environment represent some of the most complex climatic systems. The special characteristics of the animal–atmosphere system are identified, one of which is animal metabolism, defined as the process in living organisms whereby substances are transformed into tissue with an attendant release of energy and waste. The reviewer was interested particularly in the table of adult human metabolic heat production at different levels of activity which vindicated his continuing efforts at squash which merited 710 W, surpassed only by wrestling (860 W). Unfortunately, sleeping (70 W) is the lowest level of activity evaluated and so no estimate is available for cricket!

There follows an engrossing section on climates of poikilotherms, which include 'cold-blooded' animals such as fish, amphibians, reptiles and insects. Who could deny that 'the incubating queen bumble bee represents a fascinating heat balance model'? The section also contains, for example, a discussion of the circulatory systems of certain large, fast-swimming fish such as swordfish and mackerel shark which use the principle of counter-current heat exchange to allow a certain de-coupling of the flow of heat from the flow of blood. This apparently efficient method of heat conservation is also employed by some homeotherms ('warm-blooded' animals, including humans, most mammals and birds) and by industrial design engineers. A section on the climate of homeotherms includes discussion about hypo- and hyper-thermia, the different problems of thermoregulation faced by large and small animals and the methods of solution they employ.

Chapter 6 closes with an excellent section on humans with comments on windchill effects, frostbite, dehydration, and a discussion of the effects of immersion in cold water. The advice is given that the ideal posture to prolong survival is a huddle, with the arms close to the sides of the thorax and the legs drawn up to decrease heat loss from the groin. This chapter can be recommended as general reading to all walkers, climbers, yachtsmen, and others who run the risk of exposure to extreme climates.

Part III. Man-modified atmospheric environments concludes the main text with three chapters on the consequences of human interference in otherwise natural climatic systems. Intentional modification is dealt with in Chapter 7, inadvertent modification in Chapter 8 and a full, final chapter is devoted to air pollution in the boundary layer.

The book is clearly well written and stylishly and carefully produced, with only a few minor typographical and grammatical errors. There are sufficient references and a supplementary reading list for those whose appetites have been whetted but not satisfied. If a personal quibble is allowed then it con-concerns the absence of scales from many of the figures. The reviewer appreciates and applauds the author's aim to be qualitative and general wherever possible and would be forced to agree that, where omitted, the scales are not absolutely essential; however, this absence of measure is occasionally irksome and frustrating. It should also be noted that a langley is 1 cal cm^{-2} and not 1 cal $cm^{-2} min^{-1}$ as defined in Table A4.2. These very minor criticisms apart, the author has achieved his goal of producing a well-structured, illustrative and informative text which can be recommended to all who desire an introduction to the complexities and subtleties of a wide range of boundary-layer climates.

D. J. Carson

Obituary

We regret to record the death on 25 April 1979 of Mr M. C. Oughton, Scientific Officer. Mr Oughton joined the Office in 1947 and served at a number of stations at home and overseas. At the time of his death he was working at Crawley.

We regret to record the death on 14 May 1979 of Mr M. Baynes, Scientific Officer. Mr Baynes joined the Office in 1950 and served at a number of stations at home and overseas before being posted to the Central Forecasting Office (Met O 2) at Bracknell in 1971.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

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